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ENERGY TRANSFORMATION AND PULSE RATE WITH NEGATIVE MUSCULAR WORK

E. A. Mueller

Translation of: "Energieumsatz und Pulsfrequenz bei negativer Muskelarbeit," Arbeitsphysiologie, Vol. 15, 1953, pp. 196-299.

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16. Abstract

Tests employing a two-handed crank of constant revolution rate were conducted to determine performance in negative work in comparison to positive work. Three to four times higher performance was achieved in negative work.

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E. A. Mueller

By "negative work" we characterize the mechanical work necessary to extend an active muscle. Negative work always has a practical significance when movements of the limbs caused by outside forces must be slowed down in their operation, i.e., when rappelling or when going down stairs. The little known works on transformation of energy with negative work have recently been referenced by Abbot, Bigland and Ritschie and supplemented by experimentation. The authors utilized the following experimental arrangement: Two unbraked bicycle ergometers were connected by a chain in such a manner that the pedals turned in opposite directions. One test subject (TS) stepped normally forwards on one ergometer thereby turning the pedal of the other ergometer backwards. A second TS attempted to resist this backwards turn and performed as much negative work as the first person performed positive work. The elongation rate as well as the contraction rate of the same muscles were equally great. With 35 rpm the positive work consumed 3.7 times more oxygen than the negative work. This ratio increased with the number of revolutions up to 6 for 80 rpm. /196*

The result was that the transformation of energy with negative work increased much less with increasing contraction rate than in the case of positive work. In a further publication of Abbott and Bigland under exactly the same experimental conditions, the consumption of oxygen for negative work only changed with the torque and not at all in relation to the number of revolutions.

The comparison between positive and negative work is also revealed in the experiments carried out by Mueller and Hettinger and Karrasch using ordinary /197
stairs. At the same rates of speed, the same person used 13.7 kcal min to

[1]Dedicated to the Chairman of the Max-Planck Society, Professor Dr. Otto Hahn on the occasion of his 75th birthday.

*Numbers in the margin indicates pagination in the foreign text.

climb the stairs and 3.2 kcal min to go down the stairs after a period of rest. This results in a ratio of positive to negative work of 4.3, i.e., the same order of magnitude as with Abbott, et al.

A further investigation of energy transformation when riding a bicycle was undertaken by Asmussen who rode a bicycle "positively" up a treadpath with a uniform angle of gradient. In the case of negative work, the direction of rotation of the treadpedal was reversed as with positive operation so that in the case of a same setting the simular muscular tension appeared. This meant that on one occasion the muscles would be shortening and on the other occasion, they would be elongating. Asmussen also found that positive work with moderate speed 3 used up 9 times as much energy as negative work. With 100-120 rpm, oxygen consumption dropped for negative work almost to zero.

All authors accordingly found that a muscular action took much more energy when the muscles are shortened than when they are elongated. This is true with an equal expenditure of strength with motion and with equal action time. Through this it is possible to decide whether the pulse rate is controlled by energy transformation or by muscular tension. In the present work the pulse rate was therefore recorded during the work in the case of negative and positive work together with the energy transformation.

Two female test subjects carried out positive and negative cranking work with a constant revolution rate at various performance levels. The crank--ergometer used worked according to the following principle which has been previously described (E. A. Mueller, 1941). A braked shaft is simultaneously turned by a TS using a hand crank and by a three-phase motor in the same direction. When the braking capacity is lower than the capacity of the motor, but higher than the capacity of the TS, the number of rotations remains independent of the capacity of the TS since the motor with its capacity reduces its activity by as much as is added by the human. Through an appropriate intermediate part (differential), the torque transferred by the human to the shaft can be regulated and made visible. The TS can accordingly work by practice with an indicator such that torque and number of revolutions can remain constant. With negative work the TS seeks to halt the rotation of the shaft caused by the motor and, in this way, creates an additional counter-torque to the braking torque. This affects the motor performance which is again indicated and determined by the differential switched in between. By an appropriate arrangement of the chain drive between crank and motor axes, it was possible for the crank to be turned in the direction opposite to that occurring with negative work. More details on the technical design can be found in the referenced work (E. A. Mueller, 1941). The experiments were always carried out using 45 crank revolutions per minute. /198

The energy transformation was plotted according to Douglas Haldane with the pulse rate recorded according to E. A. Mueller and J. J. Reeh. The measurement of energy transformation was always performed in a steady state after work had been performed for five minutes and ten minutes. The basic transformation was likewise determined.

The following two TS (Table 1) were available:

Table 1.

TS	Age in years	Size cm	Weight kg	Basic Transformation kcal/min
Hi.	21	161	52	0.95
Ri.	20	163	55	0.97

Figure 1 shows the energy transformation in cal/mkg for positive and negative work as a function of the capacity of the two TS. With positive cranking, the energy transformation per work unit is equally high with both TS in the case of the lowest work performances. It then rises with the performance with TS Hi somewhat, whereas it only changes slightly in the case of TS Ri. The energy transformation for the unit of negative work is almost constant up to 480 mkg/min. It amounts to about 1/3 with TS Hi and, in the case of TS Ri, to about 1/4 of the transformation for positive work. Even in the case of work with an arm crank, it is found that positive work takes three to four times the energy transformation as in the case of similar negative work per revolution. That this higher transformation corresponds to a similar lower performance capacity, follows from the much lower continuous performance which is achieved with positive work. With a positive performance, the TS does not exceed 300 mkg/min whereas, with negative performance, up to 480 mkg/min was recorded.

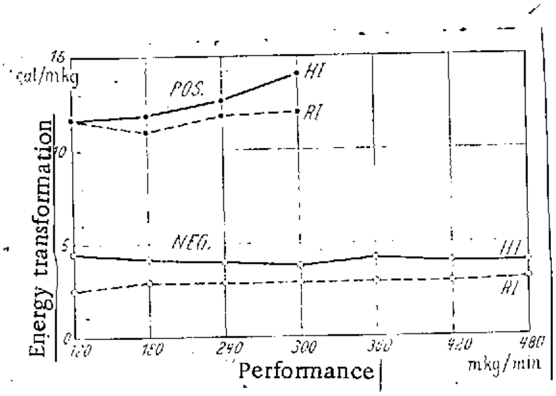

Figure 1. The Dependency of Energy Transformation on the Performance in the Case of Positive and Negative Work for Test Subjects Hi. and Ri.

Figure 2 provides us with the answer to the question whether the pulse rate is a function of the performance of the transformation. For each TS, the performance (mkg/sec) was protrayed as a function of the total O_2 consumption. TS Ri performed about four times as much with negative work and consumed the same quantity of O_2. TS Hi used up about three times as much as in the case of positive work. In order to establish the dependency of the working pulse rate on the O_2 consumption, correlation and regression values were computed for both TS as well as for both working modes. The results are listed in the Table 2. The value of the tenth working minute was used as working pulse rate. /199

Table 2.

TS	Positive Work Correlation	Positive Work Regression	Negative Work Correlation	Negative Work Regression
Hi.	0.92 ± 0.04	0.054 ± 0.002	0.74 ± 0.11	0.072 ± 0.010
	0.93 ± 0.04	0.070 ± 0.003	0.86 ± 0.05	0,087 ± 0.005

The correlation between O_2 consumption and pulse rate is very high with positive work and quite close in the case of negative work. The values of the negative work are somewhat dispersed because this working mode was an unaccustomed one. The regression values show that the pulse rate develops somewhat steeper with negative work than with positive. This difference has been statistically confirmed. The differences in performance in positive and negative work with same O_2 consumption was not important. When the regression lines of the pulse increase are plotted with O_2 consumption in Figure 2, it is clear that the pulse rate is a function of the O_2 consumption and not the muscle tension. /200

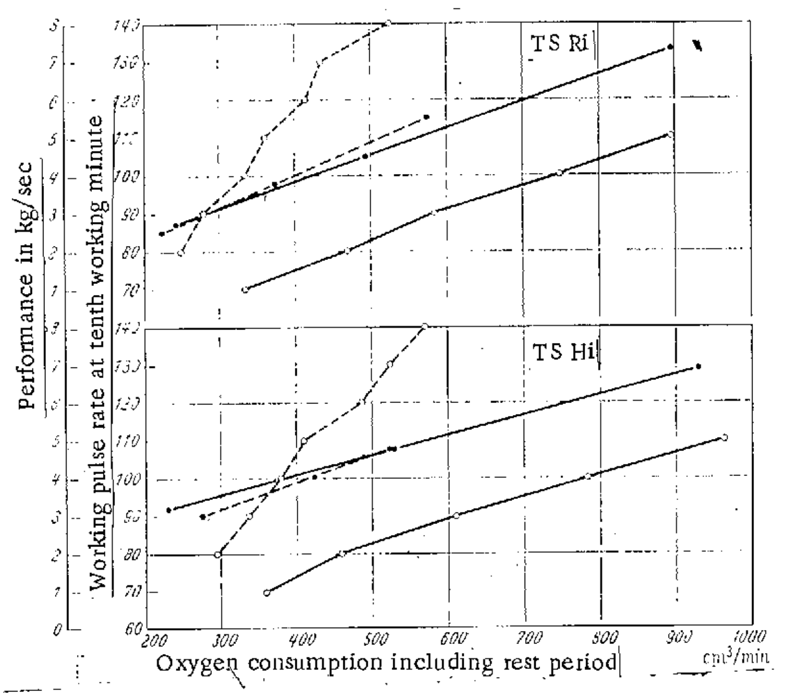

Figure 2. The Dependency of Working Order and Pulse Rate on O_2 Consumption with Positive and Negative Work for Test Subjects Hi and Ri (o-----o Positive Performance o-----o Negative Performance; •———• Pulse Rate for Positive Work, •------• Pulse Rate for Negative Work).

Summary

Using a two handed crank with constant revolution rate, two test subjects with a same consumption of O_2 achieved 3-4 times the performance with negative work than with positive work. Since the pulse rate is independent of the performance as well as whether work is being performed positively or negatively and increases proportionally to the O_2 consumption, the regulation of the working pulse rate is not a function of mechanical factors but controlled by energy transformation.

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